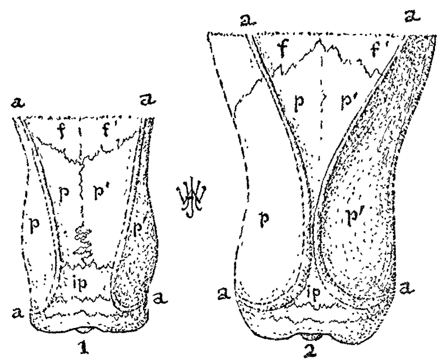
in *M. elatus*. The lateral transverse process of the fifteenth dorsal is simple at its outer extremity and does not form an oblique plate



Diagrammatic view of upper back part of skulls of (1) *M. petersoni*, (2) *M. elatus*. *aa*, superior ridges; *pp'*, parietals; *ff'*, frontals; *ip*, interparietal.

of bone projecting downward and backward and perforated by a large foramen, as is the case in the corresponding vertebra in *Moropus elatus*. The prezygapophyses of the anterior lumbar vertebræ in *M. petersoni* more closely resemble those of the preceding dorsals and are not as distinctly lumbar in their character as is the case in *Moropus elatus*. The prezygapophyses of the posterior dorsals all look more decidedly upward in *M. petersoni* than they do in *M. elatus,* and their anterior extremities are relatively far more widely separated from the superior margin of the centrum. The general structure of the feet is the same as in *Moropus elatus,* having four toes in the fore foot, the outer toe being obsolescent, and three toes on the hind foot; but the feet are slenderer and the bones not nearly so massive as in the larger species.

The type specimens representing the species are contained in the Carnegie Museum and are in part the series of bones to which have been attached in the Carnegie Museum Catalogue of Vertebrate Fossils the numbers 1703A (cervicals), 1703B (anterior dorsals), 1703C (posterior dorsals and lumbars), 1700 (mounted hind limb and pes), 1701 (a mounted fore limb and manus), 1707 (a partially restored skull).

Associated with the skull as a paratype may be mentioned the upper posterior part of a cranium of a skull designated by the figures H. C. 133, kindly loaned to the writer for study by Mr. Harold Cook. Professor E. H. Barbour in Volume III., Part 2, of the Geological Survey of Nebraska (Fig. 2) has represented a fragment of the posterior part of the skull of an immature specimen of *Moropus petersoni,* without naming it.

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Carnegie Museum,
November 13, 1908

AN ELECTRICAL RESISTANCE METHOD FOR THE RAPID DETERMINATION OF THE MOISTURE CONTENT OF GRAIN[1]

The shipping and storing qualities of grain are so dependent upon its moisture content that an accurate knowledge of the moisture in grain in storage and transit is highly desirable. This subject has been given special attention by Brown and Duvel,[2] who have described a rapid method of making such moisture determinations. Their method consists in boiling the grain in an oil having a flashing point much above the boiling point of water, condensing the water which distils off, and collecting and measuring it in a suitable graduate. Moisture determinations can, by this method, be made in about one half hour, whereas determinations in the water oven require several days. This method is, however, suitable for laboratory use only, necessitating the collecting of samples before the determinations can be made, and does not appear to be adapted to grain products such as meal and flour. At the request of the Office of Grain Standardization, the writer undertook the development of an electrical resistance method of measuring the moisture content of grain adapted to measurements in the car or elevator as well as in the laboratory, and requiring only two or three minutes for a determination. The measurements so far have been confined to wheat. The results obtained are so promising that a brief preliminary

[1] See Circular 20, Bureau of Plant Industry.

[2] Bulletin 99, Bureau of Plant Industry, U. S. Department of Agriculture, 1907.

description of the method is given. Corresponding measurements will be made for other grains as well as for flour and cornmeal. A portable apparatus suitable for measurements in cars and elevators is also being constructed.

Description of the Electrical Resistance Method for Measuring the Moisture Content of Grain.—This method consists essentially in the measurement of the resistance offered to the passage of an electric current through the grain from one metallic electrode to another. The electrical resistance decreases rapidly as the moisture content of the grain increases. The electrical resistance of wheat containing 13 per cent. of moisture is seven times that of wheat containing 14 per cent. and fifty times that of wheat containing 15 per cent. of moisture. This method, therefore, gives a very open scale, and a considerable variation in resistance can take place without seriously affecting the accuracy of the moisture determinations.

The relation between the electrical resistance and the moisture content of wheat is shown graphically in Fig. 1. The moisture percentages in this figure are plotted as ordinates and the natural logarithms of the corresponding resistances are plotted as abscissas. Five widely differing types of wheat, including soft red winter, hard red winter, No. 1 hard spring, durum, and a badly mixed wheat containing many weed seeds, were used in these determinations. The closeness with which the different points on the diagram approach the straight line drawn through them illustrates the accuracy with which moisture determinations can be made by this method. The logarithms of the resistances instead of the resistances themselves are plotted in this diagram in order to condense the diagram, and to show the linear relation between the two variables.

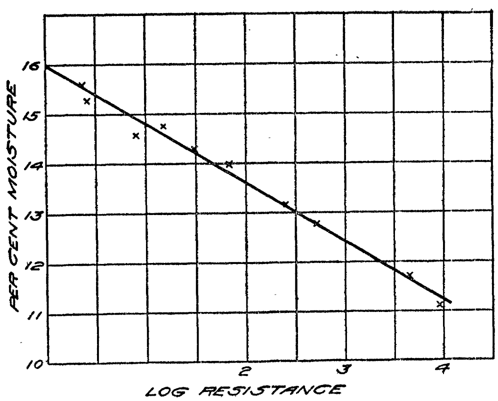

FIG. 1. Chart showing the Relation between the Moisture Content and the Electrical Resistance of Wheat. Measurements made at 75° F. For description of electrodes see text. Resistances expressed in megohms. Moisture percentages based on weight of moist grain.

Relation of Electrical Resistance to Temperature.—The electrical resistance of wheat is also dependent upon the temperature of the grain. In fact, the rapidity with which the resistance decreases as the temperature increases is quite remarkable, and greatly exceeds that occurring in most substances. The change in the electrical resistance of wheat with the temperature is shown graphically in Fig. 2, in which temperatures are plotted as ordinates and electrical resistances as abscissas. The resistance at 4° C. is seen to be eighteen times the resistance at 24° C. This curve is based upon 34 groups of measurements made upon hard red winter, soft red winter, hard red spring, durum, and a mixed wheat. Dots on the diagram refer to one sample, crosses to another, and so on. In order to construct a mean temperature resistance curve, the resistances corresponding to the different samples were all increased or decreased by an amount corresponding to the mean of the ratios of the resistances to the corresponding resistances of one curve taken as a standard. In making these determinations, the wheat, after being cooled in an ice chest, was allowed to approach the temperature of the room, and a series of resistance measurements was made as the temperature increased. The grain was in each case stirred to obtain as uniform a temperature distribution as possible before each set of measurements. Temperatures above that of the room were obtained in a similar manner by heating the grain and measuring the resistance as it cooled. It is difficult to determine the true

temperature of grain while it is being warmed or cooled in this way, which accounts for the rather wide departure of some of the points from the mean curve.

The Determination of the Moisture Content of Wheat at Different Temperatures.—By combining the data shown in Figs. 1 and 2, moisture content and resistance, not only for a single temperature, as in Fig. 1, but for temperature intervals of 5 degrees from 80° to 40° Fahr. In this chart, the moisture contents are plotted as ordinates and the logarithms of the electrical resistances as abscissas. To facilitate the use of the chart,

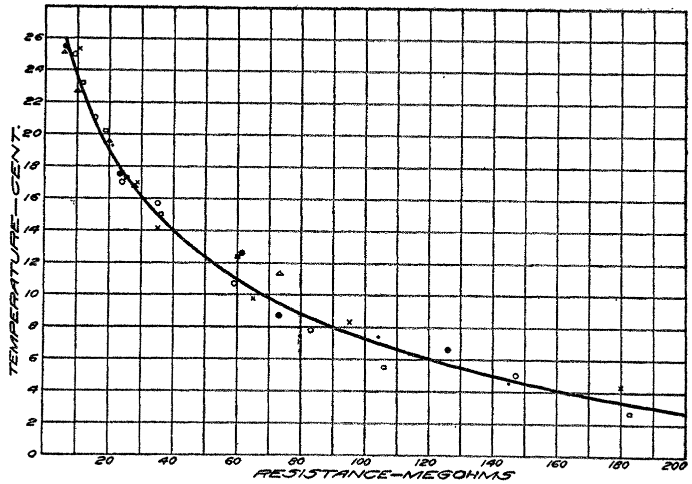

Fig. 2. Chart showing the Influence of Temperature upon the Electrical Resistance of Wheat.

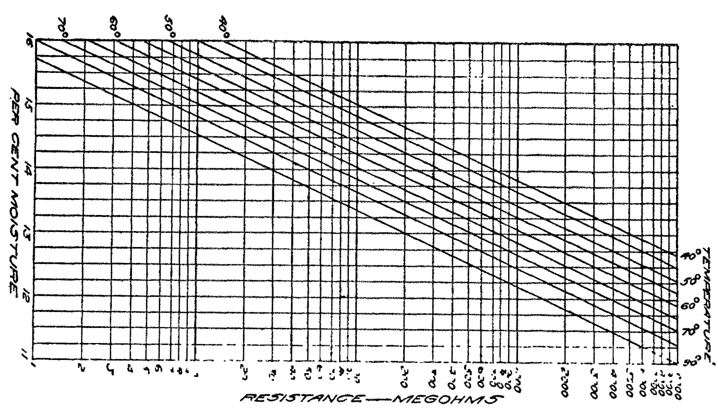

Fig. 3. Chart for Determining the Moisture Content of Wheat when the Electrical Resistance and Temperature are known. Electrodes having the same dimensions as those described in the text must be used in connection with this chart.

we can construct a chart showing the moisture content of the sample of wheat corresponding to a given electrical resistance at any temperature within the range of the experiments. Such a chart is shown in Fig. 3. This chart is similar to that of Fig. 1 except that we have here lines showing the relation between resistances are written in the place of the corresponding logarithms. To illustrate the use of the chart, suppose that a resistance of 55 megohms was observed in a given sample of wheat at a temperature of 75° F. Referring to the chart, it will be seen that the imaginary line corresponding to 55 megohms

crosses the 75° line at a point corresponding to 13.95 per cent. of moisture. This statement assumes, of course, that the measurements were made with electrodes of standard size, to which this chart is only applicable.

Apparatus for Measuring Electrical Resistance of Grain.—Unless the grain is very wet, its specific electrical resistance is very high. The resistance, while electrolytic in character, is so great that polarization is not troublesome, and measurements can be made with direct currents. The electrical apparatus required for such measurements is therefore similar to that used for testing the insulation of cables. The measurements described were made principally with a Wheatstone bridge, using a fairly sensitive galvanometer, and an electromotive force of seventeen volts. In the driest samples (below 12 per cent.) the resistance was so high, that it could not be measured by this method. For these samples, the direct deflection method was used, the galvanometer and grain resistance being connected in series with a battery having an electromotive force of ten volts.

In all the measurements described, the electrodes used consisted of two parallel one half inch round brass rods, one and one half inches between centers, and twelve inches long. These rods were kept parallel and insulated from each other by being supported in a hard-rubber block at their upper ends. Connecting wires with extra heavy rubber insulation were soldered to the two upper ends of the electrodes. The grain during measurements was held in glass battery jars five inches in diameter and eleven inches high. The height of the grain, inside measurement, was ten inches. The lower ends of the electrodes rested upon the bottom of the jar. The temperature was measured with a mercurial thermometer having a cylindrical bulb, which could be readily forced into the grain.

Before each measurement, the electrodes were removed, and the grain was packed by jarring the bottom of the container against some solid object. It is important that this precaution in packing be observed if satisfactory results are to be obtained. This will not be necessary in measurements made in cars, since the settling of the grain in transit will have reduced it to a stable condition.

Portable cable testing sets can be used for the resistance measurements necessary for moisture determinations, providing the grain is not too dry. A special testing set is now being constructed in which a resistance coil for determining the temperature of the grain is placed within one of the electrodes. A shunt box for use in connection with the direct deflection method is also being constructed.

This method is similar in principle to that developed some years ago in the Division of Soils for the measurement of the moisture content of soils.[3] The difficulties that developed in connection with that method, namely, the translocation of salts and the cracking away of the soil from the electrodes, are not encountered in the measurement of the moisture content of grain. There is a possibility that wheat grown in different localities will show a sufficient variation in salt content to affect the moisture determinations, but such variation has not been indicated in the samples so far examined.

Summary.—This paper deals with an electrical resistance method for the rapid determination of the moisture content of grain. The experiments have so far been confined to wheat. The electrical resistance of wheat containing 13 per cent. of moisture is fifty times that of wheat containing 15 per cent. The temperature of the grain must be determined. The results of the experiments indicate that the moisture content can be determined by this method with a probable error not exceeding 0.3 per cent. Measurements can be made rapidly, requiring only two or three minutes. The apparatus is portable in character so that measurements can be carried on in cars or elevators as well as in the laboratory. The use of this method in connection with other grains and grain products is now being investigated.

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BUREAU OF PLANT INDUSTRY,
October 17, 1908

[3] Bulletin 6, Division of Soils.